Environmental footprint of building elements using Life Cycle Analysis methodology

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Résumé :

La présente étude expose les résultats d'une Analyse de Cycle de Vie (ACV) comparative appliquée à un élément de construction. L'étude est motivée par le besoin de procéder à un choix de matériaux judicieux dès le stade de conception d'un produit, afin de diminuer son empreinte environnementale sur l'ensemble de son cycle de vie.

En plus de séparer l'intérieur de l'extérieur, une porte d'entrée doit satisfaire plusieurs fonctions secondaires (en termes d'opacité, d'esthétique, d'isolation acoustique et thermique, d'étanchéité, d'anti effraction etc.). Ces points doivent être correctement définis et analysés dans le cadre d'une démarche d'Analyse de Cycle de Vie en intégrant les consignes indiquées dans les normes ISO 14040 et ISO 14044.

Nous appliquons la méthodologie d'ACV au cas d'une porte d'entrée de dimensions standard devant remplir pendant 50 années les fonctions précitées. Trois nuances de bois sont prises en compte (pin de Suède, érable du Canada, bois local de type aulne), et les aspects relatifs aux impacts générés sur la totalité du cycle de vie de la porte sont analysés et discutés en détail grâce à la considération de plusieurs scénarii, en particulier, une comparaison des trois portes en bois avec une porte en PVC.

Les résultats conduisent à deux conclusions remarquables, quel que soit l'impact considéré : le bois local ne semble pas être le meilleur choix d'un point de vue environnemental, et il ressort que dans certains cas la porte en PVC est une alternative intéressante. On voit aussi que le temps d'utilisation d'une porte (durée de vie) est un point essentiel dans la démarche. Enfin, on constate que les autres composants du système considéré (poignée, charnières) ont en réalité une influence négligeable sur son cycle de vie.

Abstract :

The present study deals with the results obtained applying the LCA methodology to a building component. The approach is motivated by the need to choose adequate materials as soon as possible, i.e. at the design step, in order to reduce the environmental footprint on the whole life cycle of the product.

The main function of a front door is to separate the inside from the outside, but other functions do exist, such as to be aesthetic, insulating, opaque, 'reassuring', or to have a good weather resistance. These points must be correctly defined and analysed using the Life Cycle Assessment methodology, integrating recommendations of the ISO 14040 and ISO 14044 standards.

In our study, a door of standard dimension is chosen, for a use of fifty years. Three wooden nuances are considered (pine, maple and local alder), and we take into account the totality of the life cycle phases. The results are precisely discussed according to several scenarios are compare, particularly the comparison between three wooden front doors are a PVC door, 'achieving' the same function.

The results lead to two remarkable conclusions whatever the considered impacts. On one hand the local wooden door appears to be most 'impactant' for the environment. On the other hand, it is shown that the PVC front door can be in a few cases more environmentally friendly than the wooden doors. It is shown that the life time is an essential parameter for the discussion. Then it is noticed that the other components of the system (handle or hinges) have a negligible on the life cycle of the considered building element.

Mots clefs : Analyse de Cycle de Vie, ACV, élément de construction, empreinte environnementale, porte d'entrée

1 Introduction

If a project manager byes a building element, even if he want to limit environmental impacts, he generally doesn't consider the environmental footprint of this product during the whole life cycle. Lacking in data which could help him, he generally uses the *common sense* to make a pertinent choice in the environmental field. Then, considering the case of a front door, he will probably choose a wooden door. But it is not proved that this *common sense* will lead him to the better choice for the limitation of environmental impacts. To achieve this goal, only a reliable and recognized methodology, using an auditing standard, should be used.

The Life Cycle Assessment (LCA) is an answer to this problematic, as it is based on the ISO 14040 and ISO 14044 standards [1, 2]. Also named *cradle-to-grave approach*, this methodology aims the quantification of few environmental impacts of a product or a service, taking into account all the steps of the life cycle.

Many studies about buildings products or building elements have been published, but many of them are rather old [3, 4, 5]. The first reference deals with materials but uses the four steps of the LCA methodology to achieve significant results. In all cases, the general idea to help a project manager in the choice of building elements is the "life cycle thinking". Few case studies have been carried out, such as [6]. Two main difficulties have been pointed out: the lack of correct and updated data and the complexity of the method for the professionals. It is the reason why some studies have tried to simplify the method, either to wonder about the relevance of such simplifications [7] or to guide the user toward buildings certifications [8].

More and more studies deal with walls considered as building elements, probably because not only they are composed of heavy materials but they are generally a source of thermal losses. A recent paper compares three assessment methods based on LCA methodology [9]. Another one proposes to evaluate the environmental footprint considering a wall assembly made of different elements, which facilitates the calculation whatever the studied case [10]. Reference [11] deals with a wall using natural material and concludes that natural materials are not necessary better for the environment.

Van Nunen et al. point out the importance of time factor when studying building elements considered as services products [12]. An example is a front door with a reference service life of 15 years.

General researches dealing with LCA studies on interior doors or front doors are rather rare. Some specific studies can be found in the literature [13]. However, in the previous study for example, the results remain too general and no guidelines for environmentally friendly doors are given.

In a recent study, a LCA calculation has been partially made on front door [£1]. The present paper aims to carry on with this study. It deals with a comparative LCA study on different front doors. The idea is to evaluate the interest and the environmental footprint of the use of wood for such doors. In a first part, the LCA methodology is presented. It is then applied to evaluate the impact of the studied doors, following exactly the different steps of the methodology. The obtained results are finally discussed.

2 The Life Cycle Assessment Methodology

The Life Cycle Assessment (LCA) methodology is supposed to lead to the quantification of the environmental footprint for goods, services and processes, called *products* in the following. This approach is also called *life cycle analysis, ecobalance* or *cradle-to-grave-analysis*.

As previously indicated, a Life Cycle Assessment is the investigation and valuation of the environmental impacts of a product. It is a variant of an input-output analysis, focusing on physical rather than monetary flows. LCA is both a multi-criteria and a multi-step study, and it is "goal-dependant". This means that the goal and scope definition of the study are not only important, but can be redefined during the entire study if necessary. In the same way, every phase of a LCA is linked with at least two others.

A framework for LCA has been standardised in the ISO 14040-44 series [1, 2] by the International Organisation for Standardisation (ISO). As shown on figure 1, it consists in the following phases:

- ***Goal and scope definition****:* it defines the goal and intended use of the LCA, and scopes the assessment concerning system boundaries, function, required data quality, technology and assessment parameters.
- ***Life Cycle Inventory (LCI)****:* this is an activity for collecting data on inputs (resources, such as energy or the raw materials consumptions, and intermediate products) and outputs (emissions, wastes) for all the processes in the considered product system.

- ***Life Cycle Impact~~y~~ Assessment (LCIA):*** it is the phase of the LCA where inventory data on inputs and outputs are translated into indicators about the product system's potential impacts on the environment, on human health, and on the availability of natural resources.
- ***Interpretation****:* this crucial step is the phase where the results of the LCI and the LCIA are interpreted according to the goal of the study and where sensitivity and uncertainty analysis can also be performed to qualify the results and the conclusions.

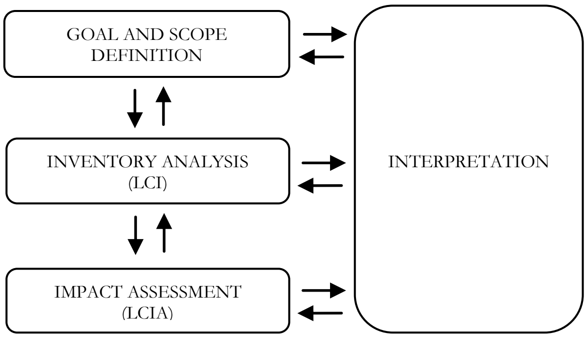

FIG. 1 – The different phases of a LCA study

Some of these phases are divided in several steps, particularly the first one (goal and scope definition) which must be made very precisely. In the following, the study will follow the four phases described above.

3 LCA methodology applied to the considered building elements

3.1 Goal and scope definition

3.1.1. Goal

The goal of the study is to compare the environmental impacts of four front doors in order to provide guidelines about choice of this category of building elements.

3.1.2. Function and Functional Unit

A front door must "realise" few functions: it must separate the inside from the outside, have a good weather resistance, and it must be aesthetically pleasing, insulating, opaque and reassuring.

The chosen front door has the following standard dimensions: 204cm high, 83cm wide and 3cm thick. Three woods are studied: pine (coming from Sweden), maple (Canada) and alder (local wood); these are compared to a door made of polyvinyl chloride (PVC). The density of each used wood is reported in table 1. The lifetime is chosen to be 50 years. However, the common lifetimes for the four studied front doors are different. The corresponding numbers of doors necessary to "achieve this function" are reported in table 1, which corresponds to the used Functional Unit. These estimated data have been taken from different joiners, except for the PVC door which is said to have a very long life time, here taken equal to 150 years.

Main material	Pine wood	maple	alder	PVC
Functional Unit	1	2	3	0.33

TABLE 1 – Functional Unit for the different doors

3.1.3. Key parameter and system boundaries

As seen above, life time will be the main key parameter.

Only the mowing part of the door is considered (including handle and hinges). In order to estimate all the contributions during the different steps of the life cycle, the *life cycle tree* of the door has been realized (figure 2). All the data of every frame of this life cycle tree have been collected and used, excepted the plantation and growth of the trees, the electricity used in the shop, the transportation of all the people who have a role in the cycle, the door packing, the transportation of the door from the use place to the end-of-life place. For the PVC door, the life cycle tree is rather different but less complicated; it is not reported here.

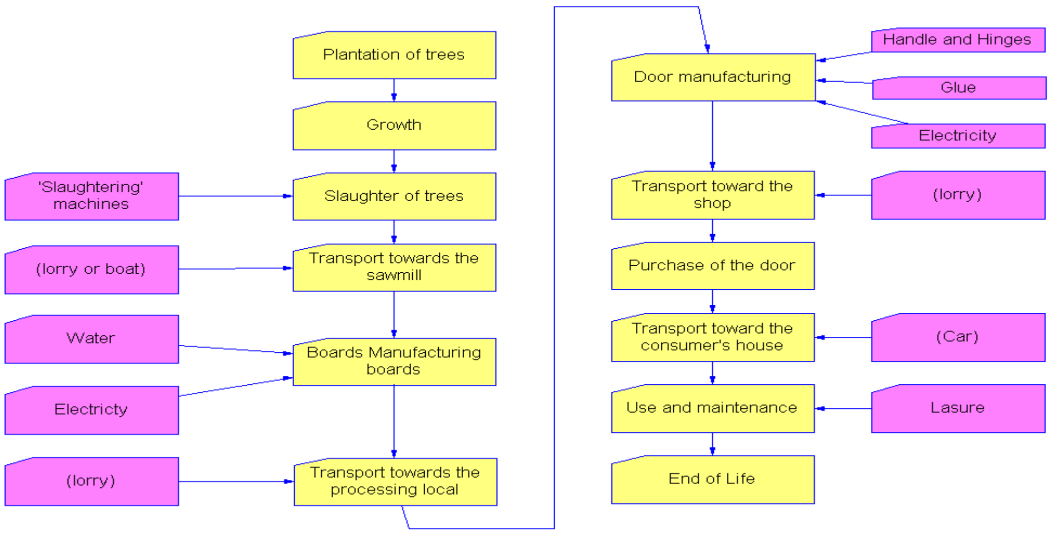

FIG. 2 – The considered life cycle tree for a wood front door

3.2 Life Cycle Inventory

The data, which take into account a consumer located near Valenciennes University, can be obtained from the authors. They are associated to the classical four steps of the LCA methodology (fig. 3).

The raw material procurement and manufacturing, namely the ***Production***, takes into account the pollutions created by the use of raw materials to build the product. The ***distribution*** phase takes into account the impacts generated during the transportation of the product towards the destination where it will be used. The ***consumer use*** corresponds here to the painting and washing of the door. For the ***end of life*** phase, handle and hinges are totally recycled, and the door is supposed to be buried (French means).

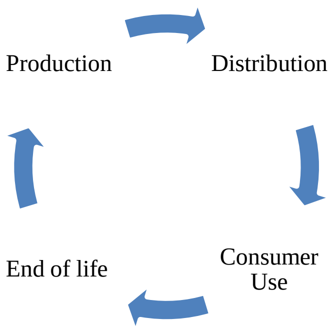

FIG. 3 – Considered steps for the study

Letter	Indicator	Unit
A	non-renewable energy consumption	MJ eq.
B	resources depletion	kg Sb eq.
C	100 year Global Warning Potential	kg CO_2 eq.
D	Acidification	kg SO_2 eq.
E	Eutrophication	kg $PO4^{2-}$ eq.
F	photochemical pollution	kg C_2H_4 eq.
G	aquatic toxicity	kg 1.4-DB eq.
H	human ecotoxicity	kg 1.4-DB eq.

TABLE 2 – Considered indicators

3.3. Impact Assessment

In order to evaluate environmental impacts from the LCI data, the Eco-invent 2.0 data-base is used [15]. The chosen indicators and the corresponding units are reported in table 2. The software which has been used is Bilan Produit ® [16].

In order to represent the different potential impacts with the same Unit, an identical Y-axis ordinate is chosen. For each indicator (letter A to H), the environmental impact is expressed in ***Points***. The ***Point*** represents the potential impact for a given indicator divided by the value of the same impact for a mean European during a day. In other words, the values of the different impacts are 'simply' normalized.

Because of the chosen end of life, some impact can be negative.

The main results giving the environmental impacts of the different front doors for the different life phases are reported on figure 4, and the different doors can be compared. The influence of some elements can be studied, for example the handle (figure 5).

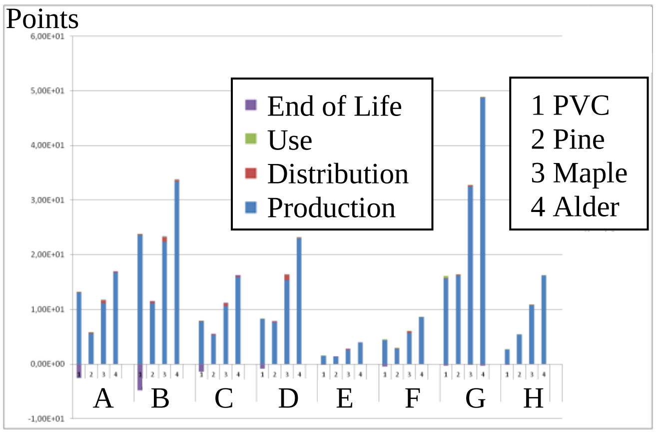

FIG. 5 –Environmental footprint by life phase

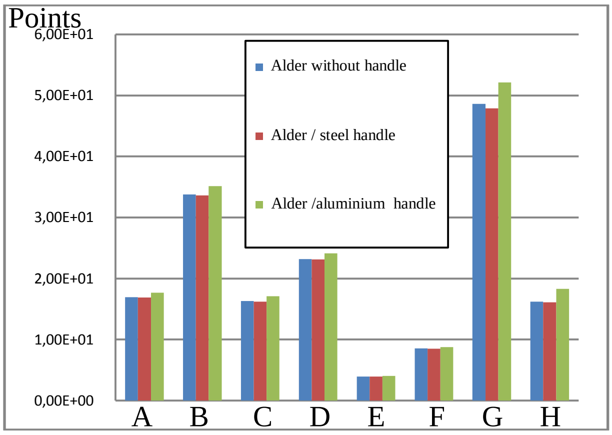

FIG. 6 – Influence of the handle

3.4. Interpretation

First, let us write that the idea is not to classify the different cases, giving to each door a global mark. This could give a global idea but would erase the main principle of the methodology: the multi-criteria analysis. Besides, such an analysis could erase the relative importance of a specific criteria compared to another one which could be negligible, because the global mark could be rather low, i.e. a front door could be considered as a "good" product for the environment with a very high value for a specific indicator.

Considering figure 5, we can see that the use phase has a negligible environmental impact, whatever the indicator and whatever the door. Then this phase could not be considered if a simplified tool was proposed. The transportation itself (distribution phase) has a low impact, compared to the production phase. The end of life can have a negative or a positive effect on the environment as the door can be partially re-used in some cases; it is particularly the case for the PVC front door. The role of the end of life step is essential for the environmental footprint. In other words, if we want to decrease notably the environmental impacts on a door, first we should act on the production phase and on the end of life, whatever the door. Concerning the production phase, the results are in good agreement with the ones obtained by Frenette et al for a wall [17]. Furthermore, the reader can refer to ref. [18] for additive information about such building elements; this study deals with the case of a different windows are lead to conclusions similar to the present ones, although the use of wood is recommended notably because of its good energy balance (the other indicators are not presented in the paper).

Another important conclusion is that the alder front door has the greater environmental footprint whatever the considered indicator. However, alder is a local material, but is said to have a smaller life time. Considering only the wood doors, it is globally shown that the choice of a local wood is not a good solution for the environment. This is mainly due to the life time of this door as reported in table 1. On the other side, the pine door seems to have the lower environmental footprint whatever the indicator, also because of the considered functional unit. The problem is the same for the PVC door which has the lower environmental footprint for some indicators, compared to wood doors, and which has the lowest environmental footprint than the alder door whatever the indicator. But the Functional Unit is 0.33 for the PVC door, compared to 3 for the alder door, and we can see that the slightest mistake or the misunderstanding of the key parameter can completely change the result and then the decision taken by a project manager.
The conclusion is that the life time is not only a key parameter but also the first thing to consider. Hereby if a PVC door, which is said to have a life time of 150 years, is changed after 25 years of use, the problem will be different and the PVC door will be the more "impactant" whatever the indicator. This conclusion can be extended to the other doors.

The influence of the handles has been evaluated (figure 6): a steel handle and another made of aluminium. The chosen door is the "worst one", considering the global footprint (see above), i.e. the alder front door. It is clear that the handle has a low influence on the footprint of a front door, whatever the handle and whatever the indicator. This is mainly due to the fact that the handle is generally recycled. So, to reduce the environmental footprint of a door, it should not be necessary to reduce the environmental footprint of the secondary elements so much.

4 Conclusion

The environmental footprint of a front door considered as a building component has been made using the LCA methodology, in order to draw guidelines. Three wooden nuances have been studied (pine, maple and local alder), and we take into account the totality of the life cycle phases.

The main result is that for such building elements, only the production phase and the end of life should be considered if a simplified tool is wanted. The influence of secondary elements such as handles can be neglected in a primary approach.

The results lead also to two remarkable conclusions whatever the considered indicators. On one hand the local wooden door appears to have a greater environmental footprint, on the other hand it is shown that the PVC front door is more environmentally friendly than the wooden doors. But these two points greatly depend on the real life of a front door and not the estimated one. Then it is shown that the end of life is a key parameter which must be carefully studied.

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